The contribution of pulse oximetry to the early detection of congenital heart disease in newborns

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Abstract Approximately half of all newborns with congenital heart disease are asymptomatic in the first few days of life. Early detection of ductal-dependant cardiac malformations prior to ductal closure is, however, of significant clinical importance, as the treatment outcome is related to the time of diagnosis. Pulse oximetry has been proposed for early detection of congenital heart disease. The aims of the present study were: 1) to determine the effectiveness of a pulse-oximetric screening performed on the first day of life for the detection of congenital heart disease in otherwise healthy newborns and 2) to determine if a pulse-oximetric screening combined with clinical examination is superior in the diagnosis of congenital heart disease to clinical examination alone. This is a prospective, multi-centre study. Postductal pulse oximetry was performed between six and twelve hours of age in all newborns of greater than 35 weeks gestation. If pulse-oximetry-measured arterial oxygen saturation was less than 95%, echocardiography was performed. Pulse oximetry was performed in 3,262 newborns. Twenty-four infants (0.7%) had repeated saturations of less than 95%. Of these infants, 17 had congenital heart disease and five of the remaining seven had persistent pulmonary hypertension. No infant with a ductal-dependant or cyanotic congenital heart disease exhibited saturation values greater or equal to 95%. *Conclusion*: postductal pulse-oximetric screening in the first few days of life is an effective means for detecting cyanotic congenital heart disease in otherwise healthy newborns.

Keywords Congenital heart disease · Newborns · Pulse oximetry

Abbreviations CHD: congenital heart disease · DA: ductus arteriosus · NPV: negative predictive value · PPV: positive predictive value · POx: pulse oximetry

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Introduction

Among all congenital malformations, cardiac lesions are the most common, with a prevalence of approximately 6 to 8 per 1,000 live births [1, 3, 4, 22, 27, 30]. Early diagnosis of congenital heart disease (CHD) is important because the delayed diagnosis of severe CHD can lead to cardiac failure, cardiovascular collapse and even death. However, early diagnosis in the first few days of life is difficult and prenatal diagnosis alone picks up less than half of all cases [2, 4, 8, 11, 17]. Clinical examination remains the most frequently used means of diagnosing CHD in newborns [4, 9, 11, 14]. In particular, the presence of a heart murmur can raise the suspicion of CHD. However, there is a large discrepancy between the incidence of heart murmurs and that of CHD in newborns; the percentage of newborns with a cardiac murmur in the first week of life ranges from 0.6% to 77%, depending on several factors, such as the examiner's clinical experience, the baby's age at examination and also the study population [3, 5, 7, 11, 12, 14, 17, 27]. Furthermore, approximately 50% of infants with CHD do not exhibit heart murmurs in the immediate postnatal period [3].

This study looks at improving the detection of CHD using pulse oximetry (POx). The premise of the study is that POx, by detecting lower than normal postductal

oxygen saturation, will alert the clinician to the possibility of a right-to-left shunt across the ductus arteriosus (DA). The aims of the present study were, therefore: 1) to analyse the effectiveness of postductal POx screening performed on the first day of life to detect structural CHD in otherwise healthy newborns and 2) to determine if POx screening combined with clinical examination is superior in the diagnosis of CHD to clinical examination alone.

Methods

This multi-centre study was conducted in four hospitals in Zurich, Switzerland: three maternity hospitals and the division of cardiology of the University's Children's Hospital. All newborn infants from 35 weeks gestation born during a one-year period underwent postductal POx measurements. Premature infants below 35 weeks of gestation, and infants with a respiratory disorder, were excluded from the study. POx was performed using the Nellcor NPB-40 handheld pulse oximeter and the Nellcor Max-N Oximax adhesive sensors. The Nellcor NPB-40 (NPB 40, Nellcor, Pleasanton, CA, USA) displays functional saturation.

Measurements, performed by the nurse at the postnatal ward, were carried out between six and twelve hours of age on either the right or left foot of the infant while the infant was quiet. As soon as the POx measurement showed a good pulse wave, the maximal value was noted. The measurement did not exceed two minutes. The functional oxygen saturation cut-off value was 95%. If saturation was below 95%, the senior house officer performed a full clinical examination of the infant; if the infant had a saturation below 90% or any signs suggestive of a CHD, echocardiography was performed immediately. In the case of an asymptomatic infant with borderline values (90–94%), a second measurement was performed four to six hours later and if saturation remained below 95%, echocardiography was performed (Fig. 1). Infants with CHD diagnosed prenatally had POx measurement prior to the postnatal echocardiography, usually between one and three hours of age.

Complete M-Mode, two-dimensional and Doppler echocardiograms were performed either at the University Hospital with an Acuson 128XP/10 (Siemens, Erlangen, Germany) with a 7.5-mHz transducer, or at the University Children's Hospital with a Sonos 5500 (Philips, Amsterdam, Netherlands), both equipped with all Doppler modalities.

CHD was defined according to Mitchell et al. [23] as "the presence of a gross structural abnormality of the heart or intrathoracic great vessels that is actually or potentially of functional significance." Thus, isolated abnormalities of no functional consequence (such as persistent left superior vena cava), congenital arrhythmias and abnormalities of the transitional circulation, such as patent ductus arteriosus, patent foramen ovale and physiologic pulmonary branch stenosis, were not considered to be indicative of CHD.

The study was approved by the local Research Ethics Committee. Information regarding the study was presented to the parents, but written informed consent was not required. All data were treated anonymously.

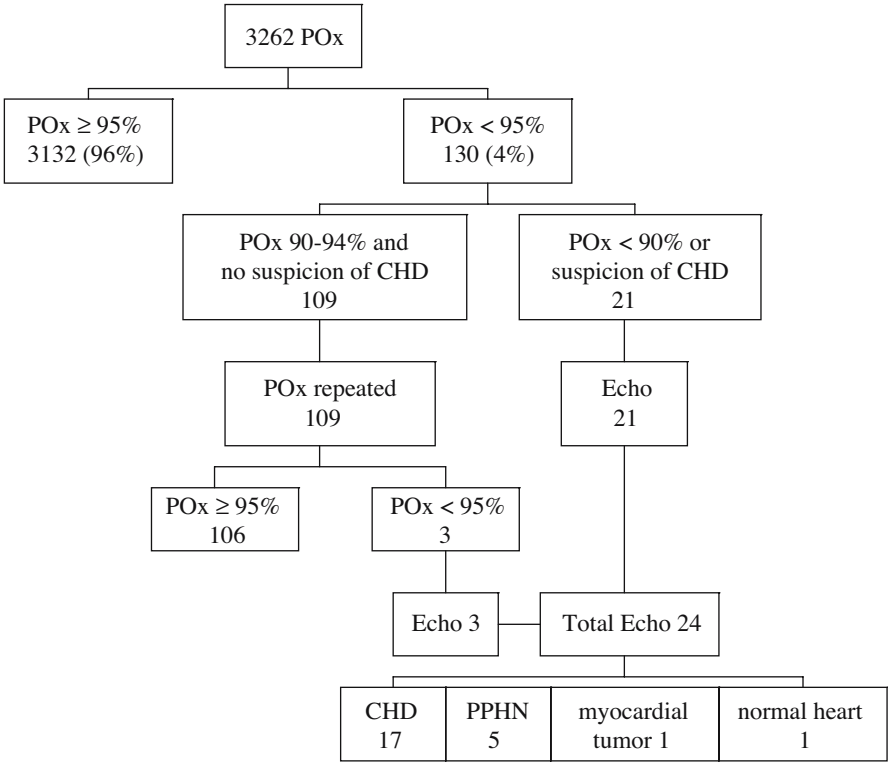

Fig. 1 POx values and progression of investigations

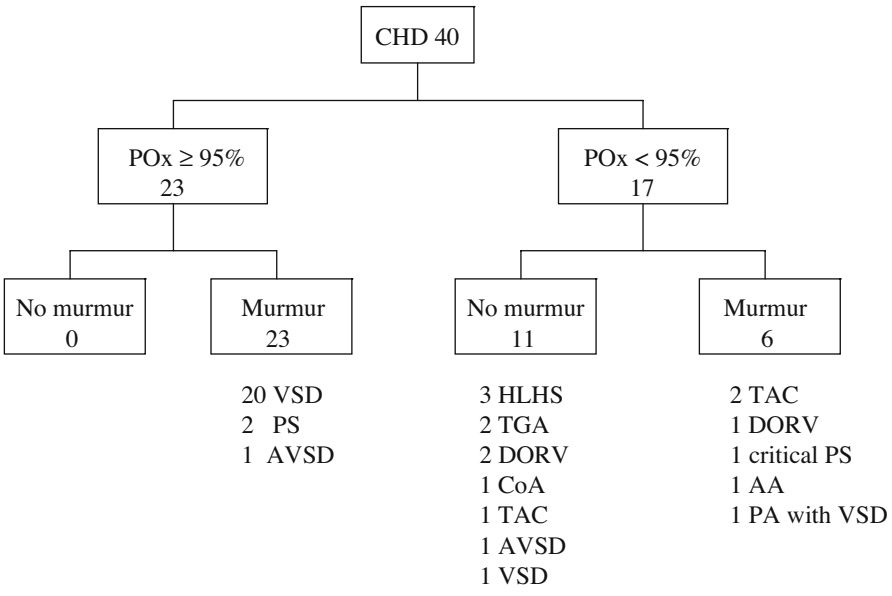

Fig. 2 Characteristics of the 40 infants with CHD. *CHD* congenital heart disease, *POx* pulse oximetry, *VSD* ventricular septal defect, *PS* pulmonary stenosis, *AVSD* atrioventricular septal defect, *HLHS* hypoplastic left heart syndrome, *TGA* transposition of the great arteries, *DORV* double outlet right ventricle, *CoA* coarticulation of the aorta, *TAC* truncus arteriosus communis, *AA* aortic atresia, *PA* pulmonary atresia

Results

The infants were born between 13 May 2003 and 12 May 2004. During that time, a total of 3,663 infants were live born. 401 infants were excluded from the study due to exclusion criteria (premature infants below 35 weeks or infants with respiratory distress). A total of 3,262 infants entered the study and had POx measurements: 1,764 at the University Hospital, 1,011 at the Zollikerberg Hospital and 487 at the Triemli Hospital. Their median gestational age was 39 weeks (range 35 to 42). Postductal POx was performed at a median age of eight hours. In 48 cases (1%), POx was performed too early, partly due to an immediate postnatal transfer to the cardiology unit or because they were discharged prior to six hours of age. In 255 cases (8%), POx was performed after 12 hours. 2,959 measurements (91%) were performed between six and twelve hours.

3,132 newborns (96%) had POx values greater or equal to 95%, while 130 newborns (4%) had POx values less than 95%. Figure 1 shows the progression of investigations in these infants. A total of 24 infants (0.7%) required echocardiography because of low POx readings. 17 of these 24 infants (71%) had CHD (Fig. 1).

Further analysis revealed that 40 newborns in total had CHD (Fig. 2). The prevalence of CHD was 12.3 per 1,000 live births. In 11 cases (28%), the diagnosis was made prenatally: all had cyanotic CHD and low POx values, but only four had a murmur at the time the echocardiography was performed. In the remaining 29 cases (72%), the diagnosis was made postnatally, either because of low POx values (6 cases), or because of a murmur (23 cases). The 23 newborns with a murmur had diagnoses of CHD at a median time of seven days (range two days to nine months) and the six newborns with low POx readings had diagnoses of CHD on the first day of life. The cardiac diagnoses of the 40 newborns are shown in Fig. 2.

The sensitivity of POx measurements for the diagnosis of cyanotic CHD in the present study was 100%, with specificity 99.7%, positive predictive value (PPV) 63% and negative predictive value (NPV) 100% (Table 1).

Routine POx reading was considered to be easy to use by the nurses. The entire procedure could usually be performed in less than five minutes while the infant was sleeping.

Table 1 Sensitivity, specificity, positive and negative predictive values of POx in detecting cyanotic CHD

	Cyanotic CHD	Non-cyanotic CHD	Total
POx positive (<95%)	15	9	24
POx negative (>94%)	0	3,238	3,238
Total	15	3,247	3,262

Sensitivity 100%, specificity 99.7%, positive predictive value 63%, negative predictive value 100%

Discussion

Effectiveness of POx screening

In the present study, POx screening in order to detect cyanotic CHD shows a very good sensitivity, specificity and NPV, but the PPV is less than optimal. A sensitivity of 100% in the detection of cyanotic CHD has not been previously reported by other authors [20, 25, 26], where at least one infant with cyanotic CHD exhibited a saturation greater or equal to 95%. Thus, it must be admitted that some false negative cases can occur. In our study, PPV is not optimal irrespective of whether or not CHD is cyanotic. Out of nine infants with positive POx screening and without cyanotic CHD, two had an acyanotic CHD. However, with right-to-left shunt across the foramen ovale and/or DA because of pulmonary hypertension, seven cases had no CHD but persistent pulmonary hypertension (5), myo-

cardial tumour (1) and a normal heart (1). In the last two cases, there was no reason for the low POx values, and we assume that human error or equipment malfunction may have been responsible.

Comparison with the literature

Comparison with the literature is difficult because the study designs, methods and denominators are not standardised [20, 25, 26]. Concerning the measurement time, Richmond et al. [26] measured at two hours of age and prior to discharge, whereas Koppel and Reich [20, 25] measured after day one and usually as close to hospital discharge as possible. Richmond analysed structural cardiac malformations, Koppel critical congenital cardiovascular malformations and Reich cyanotic CHD. Further, we decided to include CHD detected prenatally, not only to check their postductal POx prospectively, but also to analyse if they had—at the time POx was performed—symptoms that would have alert the clinician in the absence of a prenatal diagnosis. Whereas 28% of babies with CHD were detected prenatally in our population, the overall percentage of antenatal diagnosis in Switzerland is about 23% [13], which is similar to reports from other countries [8]. Thus, prenatal diagnosis of CHD should not be overestimated and could lead to a dangerous overconfidence.

Measurement time

The high number of false positive cases due to pulmonary hypertension is certainly influenced by our early time of measurement. The optimal measurement time remains uncertain. If POx screening is performed after a few days of life, there will be a reduced incidence of false positives, because of the physiologic decrease in the pulmonary vascular resistance, but a newborn with a ductal-dependant CHD could deteriorate rapidly if the DA has already closed. Measurements performed shortly after birth may lead to an increased number of echocardiograms. However, this would allow the anticipation of clinically critical situations, which can result in higher morbidity and adverse neurological sequelae [19]. Furthermore, we think that false positive POx readings due to pulmonary hypertension can be of benefit because they lead to careful clinical examination and echocardiography, and, therefore, to correct management of the patient with no delay. Lastly, there is a general tendency to shorten hospital stay and this constrains the paediatricians to examine the babies earlier after birth, which enhances the necessity of performing POx screening on the first day of life.

Saturation cut-off

Next to the time of measurement, the saturation cut-off should also be discussed. Our decision to use a 95% cut-off was taken as this reflects published normal POx values in healthy newborns [21, 24] and saturation differences observed in infants with left obstructive heart disease and obligate right to left shunt across the DA [18]. The POx values can slightly differ according to the device and depending on if it measures functional or fractional saturation, with fractional oxygen saturation being about 2% less than functional saturation [15, 26]. In addition, POx is known to overestimate arterial oxygen saturation at low saturations and underestimate it at high saturations [15, 16, 28]. The sensitivity and specificity remained quite stable using a cut-off ranging from 92% to 95%, whereas a cut-off below 92% led to a rapid decrease of sensitivity.

Role of the clinical examination

73% of infants with CHD (29/40) had a murmur at the time echocardiography was performed. Out of them, only 35% of cyanotic CHD (6/17) presented with a murmur, whereas all non-cyanotic CHD (23/23) were detected by means of a murmur. These results confirm the importance of clinical examination, but also that the presence of a murmur does not correlate well with the severity of the cardiac lesion, which has been described by other authors [3, 27, 29].

In 2002, the Swiss Society of Paediatric Cardiology published guidelines in which “pathologic murmurs” indicate a referral for cardiac evaluation [6]. Even if some paediatric cardiologists recommend cardiac investigation in any newborn with a murmur [29, 30], it remains controversial and raises the question of cost-effectiveness, considering that the majority of murmurs in newborns will be either innocent or due to minor abnormalities related to the transitional circulation [4, 9, 10, 14, 31]. Furthermore, this recommendation is impractical for maternity hospitals that do not have easy access to echocardiography equipment. In times of limited health care resources, Knowles et al. [19] published in an abstract a probabilistic estimation showing that POx screening added to clinical examination is cost-effective for the early diagnosis of CHD, which is not the case when echocardiography is used as a screening tool.

In our study, the mean time from birth to diagnosis was six days, which is short compared with the literature, and may be explained firstly by the good prenatal centralisation of the antenatal diagnosed CHD, and secondly, by the fact that, in our population, newborns were examined twice and discharged on the fourth or fifth days of life, therefore, later than in Anglo-Saxon countries.

Limitations of the study

The present study has some limitations: the sample size is small and makes the calculation of the effectiveness of POx screening difficult. Further, we assumed that all diagnoses were to be made at the division of cardiology of the University Children’s Hospital; we could, however, have missed a small number of infants diagnosed elsewhere. Lastly, inclusion of CHD detected prenatally is, in our

opinion, not a limitation, but is certainly a confounding factor.

Feasibility of POx screening

POx screening was readily accepted by the nurses. The entire measurement procedure could usually be performed in less than five minutes while the infant was sleeping. The nurses recommended implementing POx screening, a request that shows good acceptance and also that POx screening increased nurses' confidence and comfort level.

In conclusion, pulse-oximetric screening offers an effective, accurate and reliable means for detecting cyanotic CHD in asymptomatic newborns. We suggest that POx screening, added to clinical examination which is still the gold standard, should be used in maternity hospitals as a screening method for CHD. If postductal oxygen saturation is persistently below 95% or if clinical signs occur, referral to a cardiology unit is suggested.

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References

1. Abu-Harb M, Hey E, Wren C (1994) Death in infancy from unrecognised congenital heart disease. Arch Dis Child 71:3–7
2. Abu-Harb M, Wyllie J, Hey E, Richmond S, Wren C (1994) Presentation of obstructive left heart malformations in infancy. Arch Dis Child Fetal Neonatal Ed 71:F179–F183
3. Ainsworth SB, Wyllie JP, Wren C (1999) Prevalence and clinical significance of cardiac murmurs in neonates. Arch Dis Child Fetal Neonatal Ed 80:F43–F45
4. Archer N (1999) Cardiovascular disease. In: Rennie J, Roberton N (eds) Textbook of neonatology, 3rd edn. Churchill Livingstone, Edinburgh, pp 673–713
5. Arlettaz R, Archer N, Wilkinson AR (1998) Natural history of innocent heart murmurs in newborn babies: controlled echocardiographic study. Arch Dis Child Fetal Neonatal Ed 78: F166–F170
6. Bauersfeld U, Ghisla R, Günthard J (2002) Kinderkardiologie. Paediatrica 13:51–54
7. Braudo M, Rowe RD (1961) Auscultation of the heart—early neonatal period. Am J Dis Child 101:67–78
8. Bull C; British Paediatric Cardiac Association (1999) Current and potential impact of fetal diagnosis on prevalence and spectrum of serious congenital heart disease at term in the UK. Lancet 354:1242–1247
9. Danford DA (1995) Cost-effectiveness of echocardiography for evaluation of children with murmurs. Echocardiography 12: 153–162
10. Danford DA (2002) Sorting through the haystack—decision analysis and the search for heart disease among children with murmur. J Pediatr 141:465–467
11. Du ZD, Roguin N, Barak M (1997) Clinical and echocardiographic evaluation of neonates with heart murmurs. Acta Paediatr 86:752–756
12. Farrer KFM, Rennie JM (2003) Neonatal murmurs: are senior house officers good enough? Arch Dis Child Fetal Neonatal Ed 88:F147–F151
13. Fasnacht M, Pfammatter JP, Ghisla R, Sekarski N, Steinmann H, Kuen P, Guenthard J (2005) FETCH study: prospective fetal cardiology study in Switzerland. Cardiol Young 15(Suppl 2): 35A
14. Frommelt MA (2004) Differential diagnosis and approach to a heart murmur in term infants. Pediatr Clin N Am 51:1023–1032
15. Gerstmann D, Berg R, Haskell R, Brower C, Wood K, Yoder B, Greenway L, Lassen G, Ogden R, Stoddard R, Minton S (2003) Operational evaluation of pulse oximetry in NICU patients with arterial access. J Perinatol 23:378–383
16. Gidding SS (1992) Pulse oximetry in cyanotic congenital heart disease. Am J Cardiol 70:391–392
17. Gregory J, Emslie A, Wyllie J, Wren C (1999) Examination for cardiac malformations at six weeks of age. Arch Dis Child Fetal Neonatal Ed 80:F46–F48
18. Hoke TR, Donohue PK, Bawa PK, Mitchell RD, Pathak A, Rowe PC, Byrne BJ (2002) Oxygen saturation as a screening test for critical congenital heart disease: a preliminary study. Pediatr Cardiol 23:403–409
19. Knowles R, Griebsch I, Brown J, Bull C, Wren C, Dezateux C (2004) Comparing screening strategies to identify congenital heart defects in newborn babies. Arch Dis Child 89(A1):P17
20. Koppel RI, Druschel CM, Carter T, Goldberg BE, Mehta PN, Talwar R, Bierman FZ (2003) Effectiveness of pulse oximetry screening for congenital heart disease in asymptomatic newborns. Pediatr 111:451–455
21. Levesque BM, Pollack P, Griffin BE, Nielsen HC (2000) Pulse oximetry: what's normal in the newborn nursery? Pediatr Pulmonol 30:406–412
22. McCrindle BW (2004) The prevalence of congenital cardiac lesions. In: Freedom RM, Yoo SJ, Mikailian H, Williams WG (eds) The natural and modified history of congenital heart disease. Blackwell Publishing, Oxford, UK, ISBN 1-4051-0360-4, pp 8–15
23. Mitchell SC, Korones SB, Berendes HW (1971) Congenital heart disease in 56,109 births. Incidence and natural history. Circulation 43:323–332
24. O'Brien LM, Stebbens VA, Poets CF, Heycock EG, Southall DP (2000) Oxygen saturation during the first 24 hours of life. Arch Dis Child Fetal Neonatal Ed 83:F35–F38
25. Reich JD, Miller S, Brogdon B, Casatelli J, Gompf TC, Huhta JC, Sullivan K (2003) The use of pulse oximetry to detect congenital heart disease. J Pediatr 142:268–272
26. Richmond S, Reay G, Abu-Harb M (2002) Routine pulse oximetry in the asymptomatic newborn. Arch Dis Child Fet Neonatal Ed 87:F83–F88
27. Richmond S, Wren C (2001) Early diagnosis of congenital heart disease. Semin Neonatol 6:27–35
28. Schmitt HJ, Schuetz WH, Proeschel PA, Jaklin C (1993) Accuracy of pulse oximetry in children with cyanotic congenital heart disease. J Cardiothorac Vasc Anesth 7:61–65
29. Silove ED (1994) Assessment and management of congenital heart disease in the newborn by the district paediatrician. Arch Dis Child Fetal Neonatal Ed 70:F71–F74
30. Wren C, Richmond S, Donaldson L (1999) Presentation of congenital heart disease in infancy: implications for routine examination. Arch Dis Child Fetal Neonatal Ed 80:F49–F53
31. Yi MS, Kimball TR, Tsevat J, Mrus JM, Kotagal UR (2002) Evaluation of heart murmurs in children: cost-effectiveness and practical implications. J Pediatr 141:504–511